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Abstract: OBJECTIVE To describe the topographic anatomy of surgically accessible surfaces of the human thalamus as a guide to surgical exploration of this sensitive area. METHODS Using the operating microscope, we applied the fiber microdissection technique to study 10 brain specimens. Step-by-step dissections in superior-inferior, medial-lateral, and posterior-anterior directions were conducted to expose the surfaces and nuclei of the thalamus and to investigate the relevant anatomic relationships and visible connections. RESULTS There were 4 distinct free surfaces of the thalamus identified: lateral ventricle surface, velar surface, cisternal surface, and third ventricle surface. Each is described with reference to recognizable anatomic landmarks and to the underlying thalamic nuclei. The neural structures most commonly encountered during the surgical approach to each individual surface are highlighted and described. CONCLUSIONS Observations from this study supplement current knowledge, advancing the capabilities to define the exact topographic location of thalamic lesions. This improved understanding of anatomy is valuable when designing the most appropriate and least traumatic surgical approach to thalamic lesions. These proposed surface divisions, based on recognizable anatomic landmarks, can provide more reliable surgical orientation.

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Original Article

Short title: TOPOGRAPHIC ANATOMY OF THE THALAMUS

Topographic Classification of the Thalamic Surfaces Related to Microneurosurgery: A White Matter Fiber Microdissection Study

Carlo Serra[1, 2]

Uğur Türe[1, *]

drture@yahoo.com

Niklaus Krayenbühl[2]

Gülgün Şengül[3]

Dianne C.H. Yaşargil[1]

M. Gazi Yaşargil[1]

[1]Department of Neurosurgery, Yeditepe University School of Medicine, Istanbul, Turkey

[2]Department of Neurosurgery, UniversitätsSpital Zürich, Zürich, Switzerland

[3]Department of Anatomy, Ege University School of Medicine, İzmir, Turkey

*To whom correspondence should be addressed: Uğur Türe, M.D.

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Objective

To describe the topographic anatomy of surgically accessible surfaces of the human thalamus as a guide to surgical exploration of this sensitive area.

Methods

Using the operating microscope, we applied the fiber microdissection technique to study 10 brain specimens. Step-by-step dissections in superior-inferior, medial-lateral, and posterior-anterior directions were conducted to expose the surfaces and nuclei of the thalamus and to investigate the relevant anatomic relationships and visible connections.

Results

There were 4 distinct free surfaces of the thalamus identified: lateral ventricle surface, velar surface, cisternal surface, and third ventricle surface. Each is described with reference to recognizable anatomic landmarks and to the underlying thalamic nuclei. The neural structures most commonly encountered during the surgical approach to each individual surface are highlighted and described.

Conclusions

Observations from this study supplement current knowledge, advancing the capabilities to define the exact topographic location of thalamic lesions. This improved understanding of anatomy is valuable when designing the most appropriate and least traumatic surgical approach to thalamic lesions. These proposed surface divisions, based on recognizable anatomic landmarks, can provide more reliable surgical orientation.

Key words: Anatomy; Fiber microdissection; Thalamic peduncles; Thalamus; White matter

Introduction

The thalamus forms part of the diencephalon and comprises 2 ovoid interconnected groups of nuclei that are linked cranially with the telencephalon and caudally with the mesencephalon.[1-5] The thalamus is generally regarded as a portal for transfer of various processes to the telencephalon and plays an important role in somatic, vegetative, and cognitive functions.[6,7] According to Herrick's columnar model of 1910,[8] the diencephalon is subdivided anatomically along a dorsoventral direction, and the resulting sections are termed epithalamus, dorsal thalamus, ventral thalamus, and hypothalamus. However, the prosomeric model of Puelles and Rubenstein in 2002[9,10] has refuted this anatomic version (Table 1). According to their research, based on gene expression studies, the diencephalon is organized in a rostrocaudal pattern of embryologic segmental units, or prosomers. The term "thalamus," which appears in all neurosurgical literature, corresponds to the main groups of nuclei enclosed within the external medullary lamina.

Table 1 Comparison of Columnar and Prosomeric Models

Columnar Model*	Prosomeric Model†		
Pretectum (part of mesencephalon)	Primary prosencephalon	P1	Pretectum
Epithalamus - Habenula - Pineal gland		P2	Epithalamus - Habenula - Pineal gland Thalamus - Anterior, ventral, medial, lateral, intralaminar, midline, and posterior nuclear group - Lateral and medial geniculate bodies
Dorsal thalamus - Anterior, ventral, mediodorsal, lateral, posterior, midline, intralaminar nuclear group - Lateral and medial geniculate bodies ("metathalamus")			
Ventral thalamus - Reticular nucleus - Zona incerta - Pregeniculate nucleus - STN		P3	Prethalamus - Reticular nucleus - Pre- and subgeniculate nucleus - Field H of Forel - Zona incerta - SN
Hypothalamus	Secondary prosencephalon	HP1	Evaginated telencephalon, retrotuberal region,

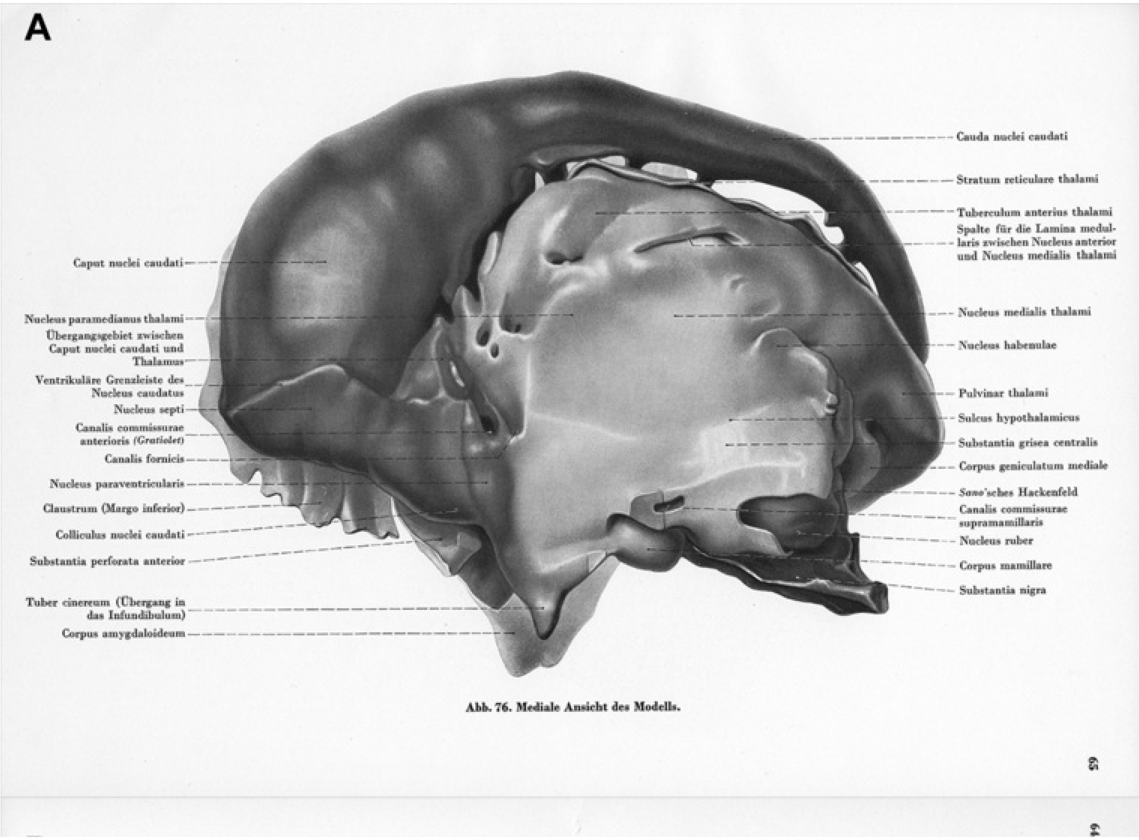
- Preoptic, anterior, tuberal, mammillary region			retromammillary region, STN
Telencephalon		HP2	Preoptic area, tuberal region, neurohypophysis, mammillary bodies

STN, subthalamic nucleus; SN, substantia nigra.

* Adapted from Herrick CJ. The morphology of the forebrain in amphibia and reptilia. *Journal of Comparative Neurology and Psychology*. 1910;20:413-547.[8]

† Adapted from Puelles L, Rubenstein JL. Forebrain gene expression domains and the evolving prosomeric model. *Trends Neurosci*. 2003;26:469-476.[9]

Current understanding of the three-dimensional macroscopic anatomy and gross connections of this region is the culmination of a long process of successive discoveries and conceptualizations contributed by numerous prominent anatomists.[11-13] Technologic advances and investigational improvements transferred the focus of most studies to the internal microarchitecture of the thalamus and its functional connections.[11,14,15] Despite the advanced technology available today, most of the applicable literature concentrates on the anatomy of nonhuman vertebrates only.[6,10,16] Descriptions of the three-dimensional macroscopic anatomy of the human thalamus and its connections are sketchy. Some publications concentrated solely on the morphologic aspects of the thalamus,[1,2] illustrated by drawings, with some being particularly notable because of their precision and artistic interpretation (Figures 1 and 2).[17,18] Other studies described only parts of the diencephalon, often incidentally in the context of studies dedicated to other anatomic or surgical topics.[19,20]



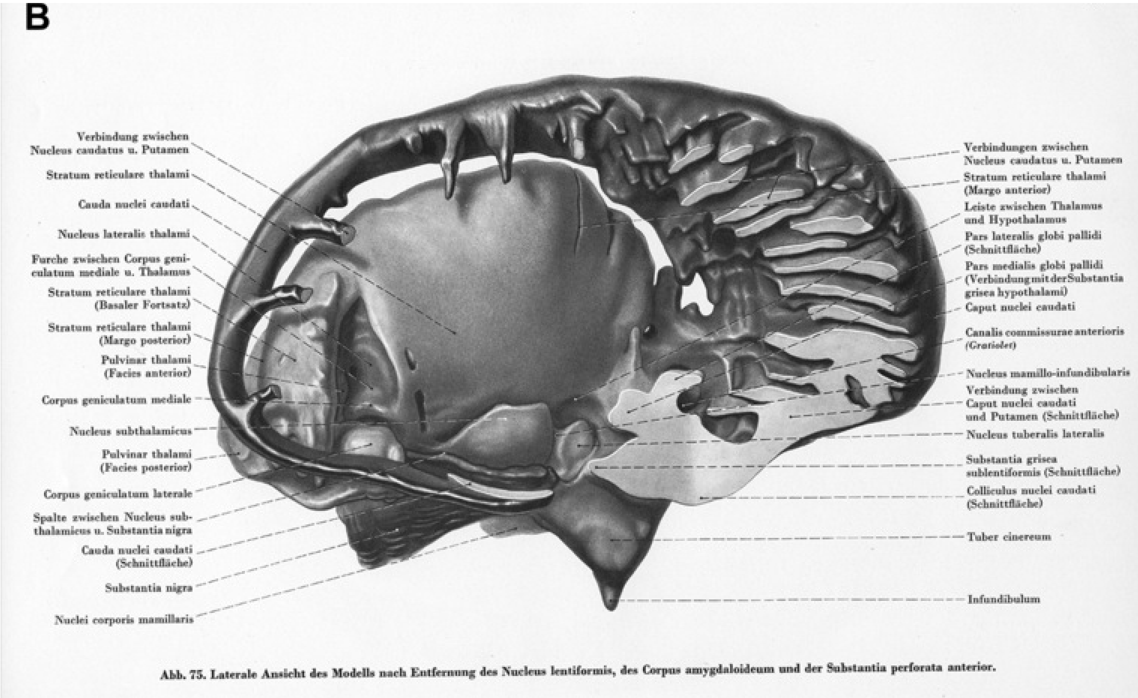
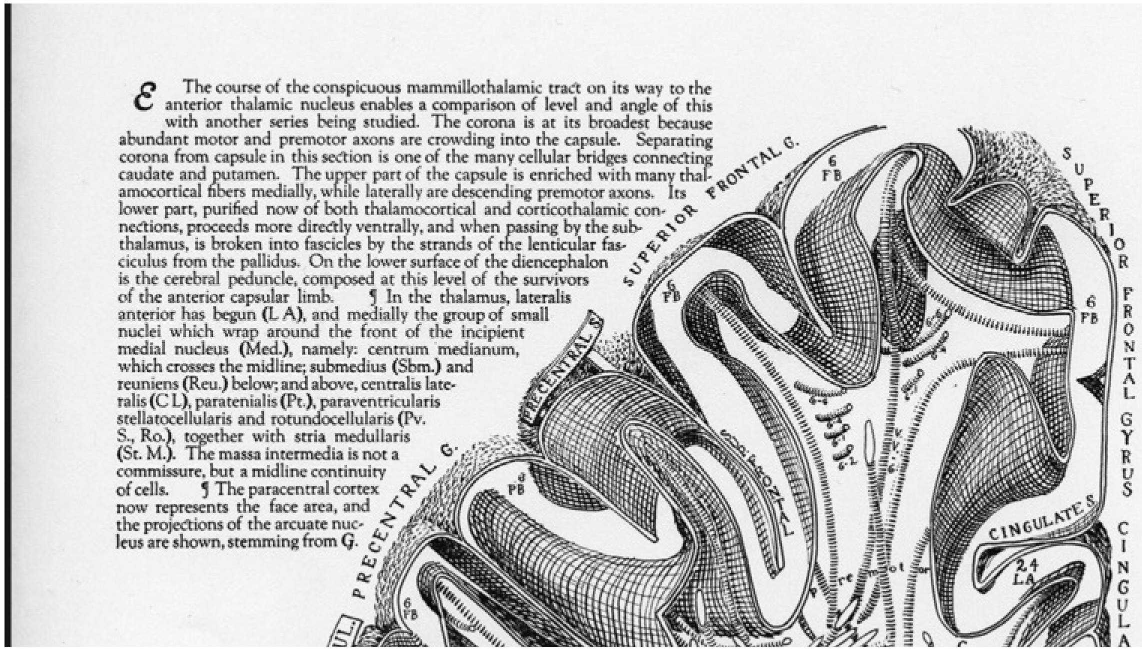


Figure 1 Artistic depiction from medial (**A**) and lateral (**B**) angles showing the three-dimensional relationships of the thalamus with surrounding structures. The drawing is based on a model in wax and brass created by Josef Klingler in 1941[17] and later popularized in the atlases of Wolf-Heidegger and Pernkopf.[19]



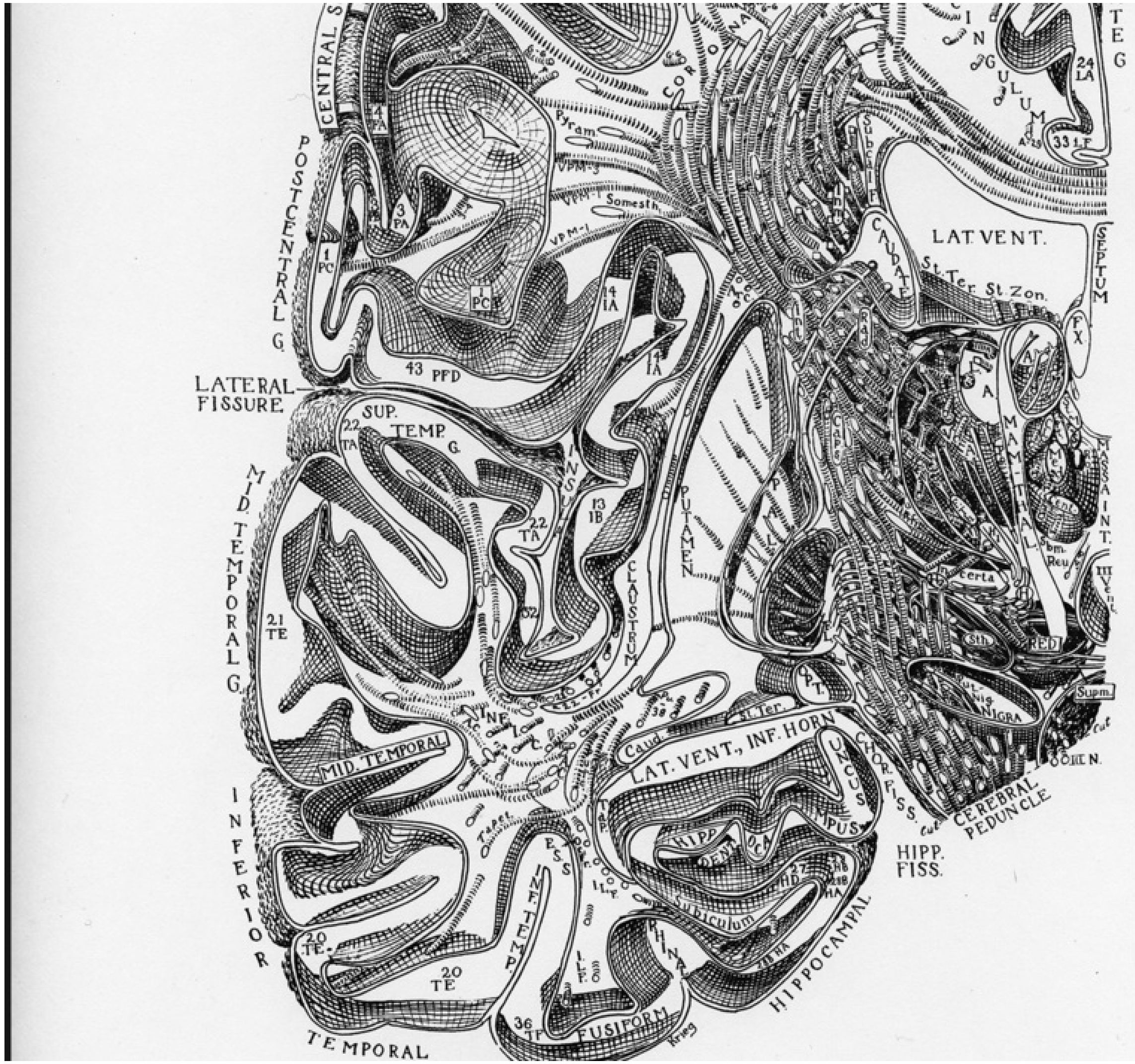


Figure 2 One of the most exhaustive and detailed depictions of the cerebral and thalamic connections is that reported by Krieg and Mark in their outstanding work *Architectonics of Human Cerebral Fiber Systems*.[17] The attention paid to rendering the three-dimensional reciprocal relationships of fiber tracts is remarkable; fiber tracts pertaining to the thalamic radiations are represented with square sections. The mammillothalamic tract running between the medial and lateral groups of nuclei is also depicted.

Performing precise and effective surgery for lesions in this region relies on understanding and assimilating the anatomy of the thalamus. The lack of basic, organized anatomic knowledge related to the thalamus no doubt is a strong contributing factor of the conservative attitude generally adopted by neurosurgical specialties relating to the treatment of thalamus lesions. For example, in oncologic neurosurgery, biopsy or subtotal resection followed by adjuvant therapy (if indicated) is often the favored approach,[21-25] despite the awareness that radical tumor resection is an established and positive prognostic factor in the management of gliomas.[26]

During the early era of neurosurgery, the disappointing outcomes and adverse results after surgery of thalamus lesions[27,28] inevitably influenced the prevailing pessimistic attitude toward this particular location. Establishing the precise anatomic structure of the thalamus, defining its connections, and identifying the surrounding anatomy and anatomic landmarks will augment neurosurgeons' knowledge and promote confidence to approach this area. A comprehensive knowledge of anatomy is essential to successfully performing precise microneurosurgical procedures.[29,30] The aim of the present study is to describe the topographic anatomy of the human thalamus. A white matter fiber dissection study demonstrates the surfaces of the thalamus that are surgically accessible. In addition, the relationships of these surfaces to the thalamic nuclei, neighboring neural structures, and fiber tracts are highlighted.

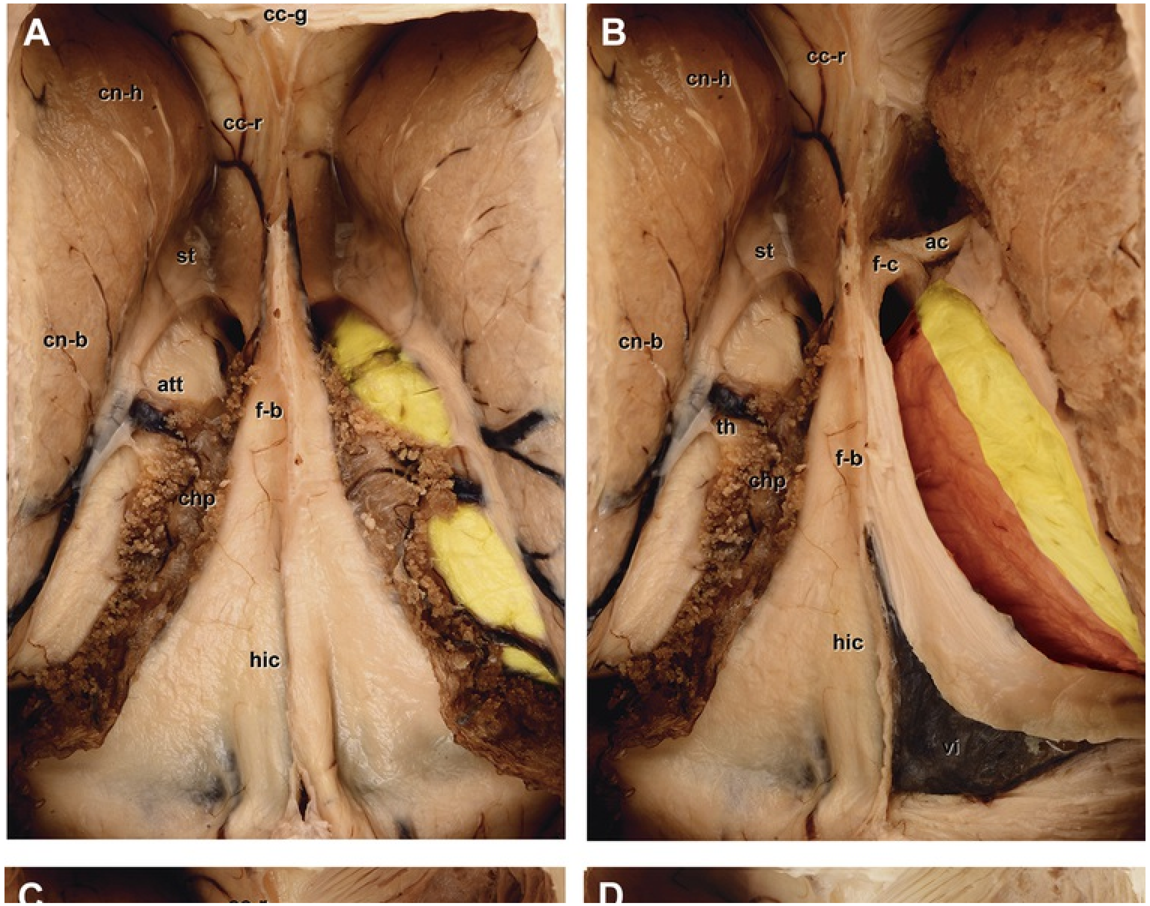
Materials and Methods

The topographic anatomy of the thalamus was studied in 10 brain specimens (20 hemispheres) obtained from routine autopsies. Before dissection, the fresh brain specimens were prepared according to Klingler's protocol.[31,32] First, they were fixed in a 10% formaldehyde solution for at least 2 months. Then the vessels and arachnoid were carefully removed, and the specimens were frozen at −20°C for at least 1 week. Before dissection, the specimens were immersed in water at room temperature and allowed to thaw. As described in a previous publication,[33] the fiber microdissection technique was applied using the operating microscope at high magnification. The tools comprised a suction system with a suction regulator, watchmaker's forceps, and wooden spatula. Stepwise dissection along standard anatomic axes—posterior to anterior, medial to lateral, and superior to inferior—exposed the thalamus and its relevant anatomic relationships.

Results

Superior Aspect

Implementing sharp dissection, the superior frontal gyri are removed bilaterally, together with the paracentral lobule and the precuneus, to expose the cortex of the cingulate gyri. After decortication, the long association fibers of the cingulate gyri are exposed and are peeled away to reveal the underlying corpus callosum. This structure is covered by a thin layer of gray matter (the indusium griseum or supracallosal gyrus), embedded with very fine myelinated longitudinal fibers. These fibers are also known as the stria longitudinalis medialis corporis callosi (or stria of Lanci) and lateral longitudinal stria. The commissural fibers of the corpus callosum are dissected and severed from the rostrum as far as the splenium to open the roof of each lateral ventricle. Under sharp dissection, the septum pellucidum, which separates the 2 ventricles, is removed. The floor of the body of the lateral ventricle and its structures are now visible. These are, from lateral to medial, the lateral ventricle surface of the thalamus, the choroid plexus, and the fornix (Figure 3A).



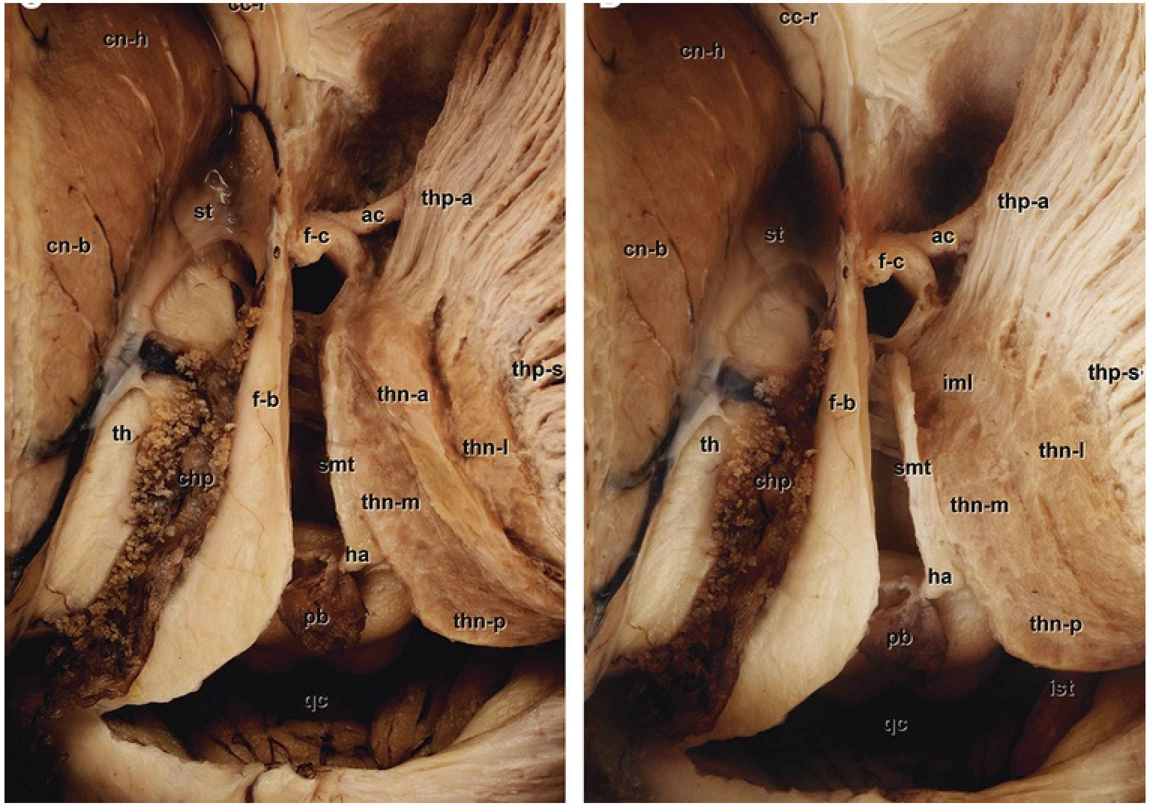


Figure 3 Dissection of the superior aspect. The left side is kept intact as a reference. For the sake of clarity, bilateral structures are labeled on 1 side only. (**A**) Appearance of the floor of the body of the right and left lateral ventricles. The septum pellucidum separating the ventricles has been removed. The visible thalamic surface (lateral ventricular surface) is highlighted in yellow on the right side. (**B**) Removal of the choroid plexus and ependyma in the right ventricle and dissection of the anterior and medial border of the lateral ventricular surface. The opening of the choroidal fissure allows the surgeon to gain access into the velum interpositum and partly expose the velar surface (highlighted in red). (**C**) Dissection at the lateral border of the lateral ventricular surface with removal of the caudate nucleus to display the fibers of the thalamic peduncles. Medially, the removal of the fornix allows a view of the whole velar surface. The removal of the zonular layer allows one to appreciate the relationship of the surfaces with the underlying thalamic nuclear groups. (**D**) Intrathalamic dissection. The anterior nuclear group can be dissected along the internal medullary lamina, which is barely visible as a faint white line. ac, anterior commissure; att, anterior thalamic tubercle; cc-g, genu of the corpus callosum; cc-r, rostrum of the corpus callosum; chp, choroid plexus; cn-b, body of the caudate nucleus; cn-h, head of the caudate nucleus; f-b, body of the fornix; f-c, column of the fornix; ha, habenula; hic, hippocampal commissure (commissure of the fornix); ist, isthmus of the cingulate gyrus; pb, pineal body; qc, quadrigeminal cistern; smt, stria medullaris thalami; st, stria terminalis; th, thalamus; thn-a, anterior thalamic nuclear group; thn-l, lateral thalamic nuclear group; thn-m, medial thalamic nuclear group; thn-p, posterior thalamic nuclear group; thp-a, anterior thalamic peduncle; thp-s, superior thalamic peduncle; thp-p, posterior thalamic peduncle; vi, velum interpositum.

The lateral ventricle surface of the thalamus vaguely resembles a triangle, with an anteromedial base at the foramen of Monro and 2 limbs converging posterolaterally toward the atrium. The stria terminalis, which courses in the striothalamic sulcus separating the thalamus from the caudate nucleus, forms the lateral limb, and the choroid plexus, more precisely the taenia choroidea (the thalamic attachment of the choroid plexus), forms the medial limb. The narrow anterior portion of the lateral ventricle surface mostly corresponds to the anterior thalamic tubercle.

The ependyma of the entire cavity of the lateral ventricle is stripped away, and the dissection is continued layer by layer at the 3 borders of the lateral ventricle surface of the thalamus. At the anterior border, the septal gray matter is removed, and the terminal fibers of the stria terminalis are dissected and severed. Thus, the column of the fornix is exposed medially as well as the transverse-oriented fibers of the anterior commissure, which extend from the median line and later continue laterally beneath the caudate nucleus into Gratiolet canal (Figure 3B).

Dissection proceeds at the medial border of the thalamic surface with the removal of the choroid plexus, which is severed at both attachments (taenia choroidea laterally and taenia fornicis medially). This maneuver opens the choroidal fissure, allowing access inferomedially into the velum interpositum and more posteriorly into the quadrigeminal cistern, and by exposing the velar surface and part of the cisternal surface of the thalamus discloses a larger view of the thalamic surface medially. At the taenia choroidea, the thalamic surface continues curving inferiorly under the fornix, then medially toward the stria medullaris thalami, and posteriorly to the tip of the pulvinar to form the lateral wall of the velum interpositum. The body of the fornix, to which the superior tela choroidea is attached, forms the roof of the velum interpositum and prevents medial exposure of the thalamus (Figure 3B).

The whole fornix is removed on the right side (Figure 3C), maximizing exposure of the thalamus. Medially, the whole velar surface of the thalamus is now visible, from the taenia choroidea superoinferiorly as far as the stria medullaris thalami and anteroposteriorly from the foramen of Monro to the habenular commissure. The stria medullaris thalami supplies an attachment to the inferior tela choroidea and marks the border between the velar surface and the third ventricle surface of the thalamus. More posteriorly, the whole superior surface of the pulvinar is also exposed together with the quadrigeminal cistern.

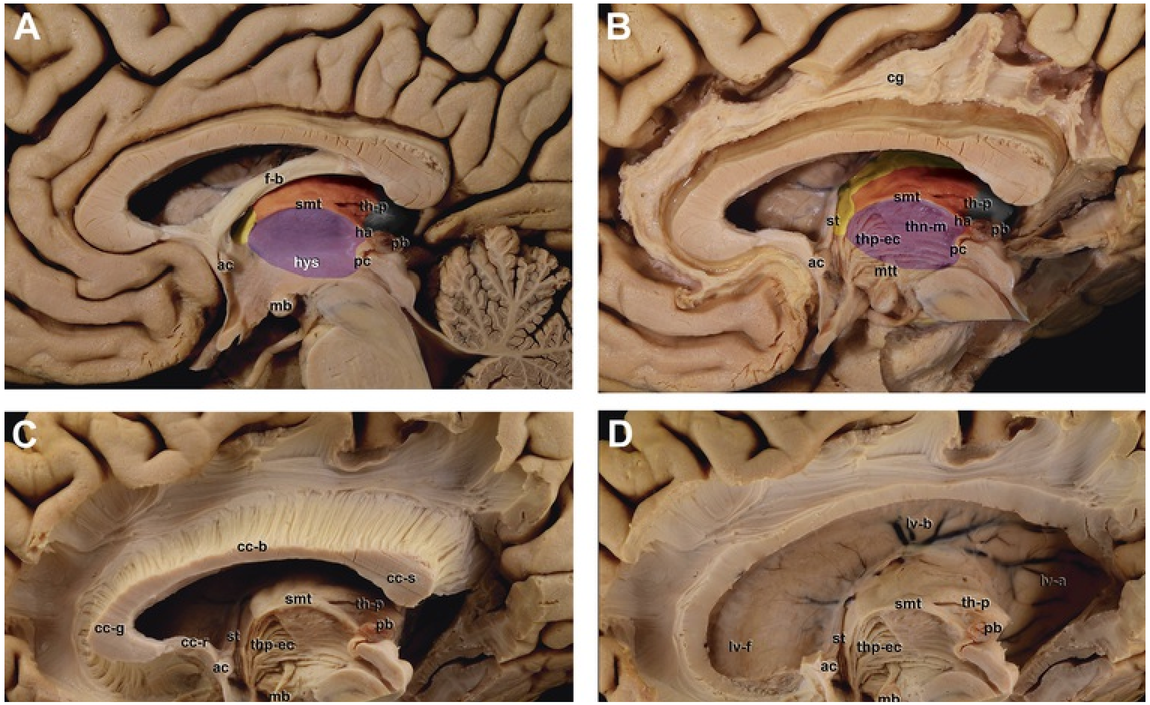
Dissection continues at the lateral border of the thalamic surface with removal of the caudate nucleus and of the zonular layer of the thalamus. Lateral to the stria terminalis, the first dissection phase exposes the course of many radially arranged fibers of the thalamic peduncles, which connect the thalamus with the telencephalon. These fibers emerge fan-like in the narrow curved area beneath the stria terminalis. The second dissection phase discloses the gray matter of the thalamic groups of nuclei.

The anterior thalamic tubercle, which corresponds to the anterior thalamic group of nuclei, supplies an attachment, at its medial aspect, to the taenia choroidea and manifests as a characteristic bulge that is located in a cleft between the medial and posterior thalamic group of nuclei medially and the lateral thalamic group of nuclei laterally. Dissecting the anterior thalamic tubercle from the rest of the thalamus (Figure 3D) is not complicated if the cleavage plane along the internal medullary lamina is followed. After the anterior group of nuclei has been removed, this cleavage plane can be visualized as a faint white line separating the lateral from the medial groups. The thalamocortical fibers that originate from the medial group of nuclei pass anterolaterally in this plane, between the lateral group of nuclei inferiorly and the anterior group of nuclei superiorly, to reach the internal capsule.

Medial Aspect

The third ventricle surface (i.e., the medial surface of the thalamus bordering on the third ventricle) is immediately visible on inspection of the medial aspect of a hemisphere. This surface has an oval shape. The superior border is demarcated anterosuperoposteriorly by the stria medullaris thalami, which course from the foramen of Monro posteriorly to the habenular commissure. The remainder of the posterior border, in a cranial-to-caudal direction, is demarcated by the pineal recess and the posterior commissure. The inferior border is defined by the hypothalamic sulcus, a shallow groove originating from the superior limit of the cerebral aqueduct, just beneath the posterior commissure, culminating in the foramen of Monro.

Dissection begins at the superior margin of the third ventricle surface. The arachnoidal layers are separated and removed. The superior tela choroidea and inferior tela choroidea of the velum interpositum, which are attached to the inferior surface of the fornix and to the stria medullaris thalami, respectively, are also removed. The septum pellucidum is detached from the body of the fornix and the corpus callosum. This dissection exposes the velar surface of the thalamus, described previously (Figure 3B and C), and the medial surface of the pulvinar, which is part of the cisternal surface (Figure 4A).



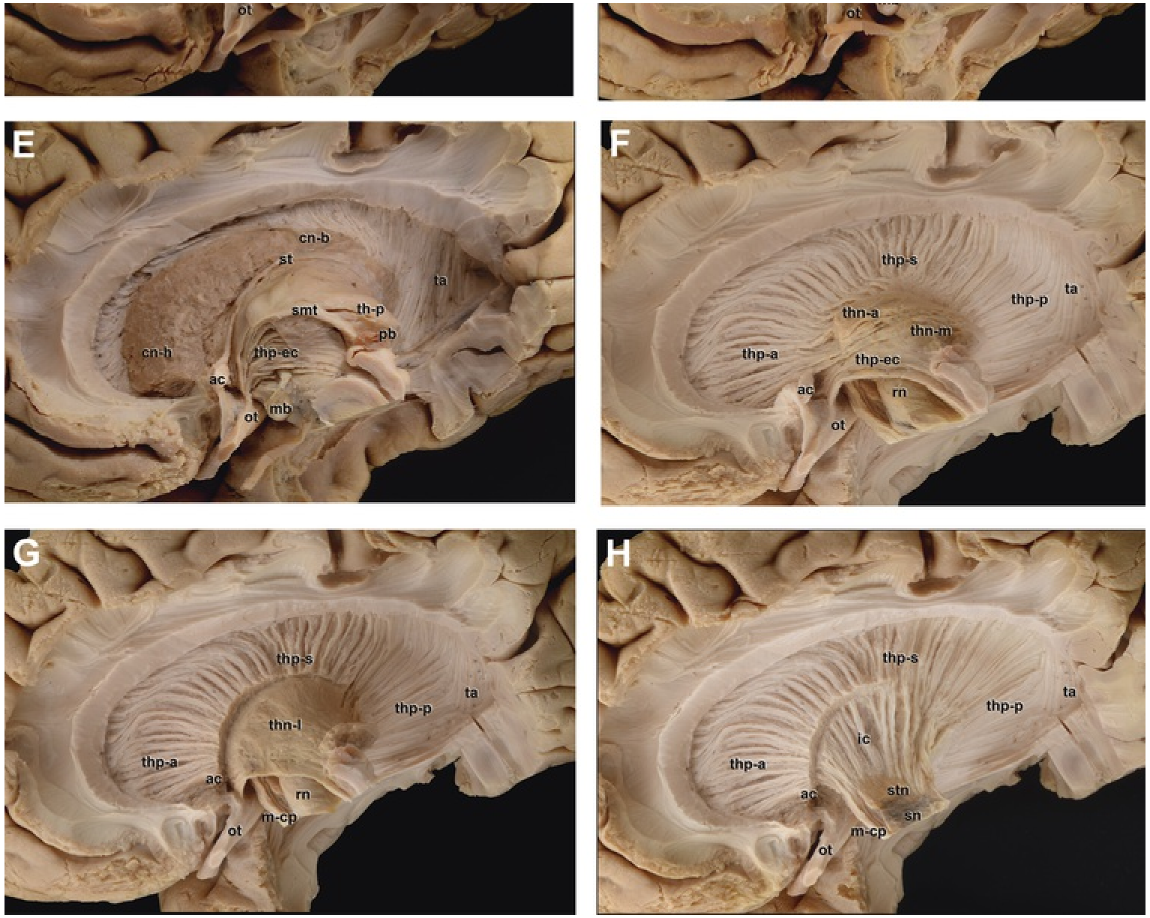


Figure 4 Stepwise dissection of the medial aspect. (**A**) Medial view of a right hemisphere after removal of the septum pellucidum and the tela choroidae of the velum interpositum. View of the third ventricle surface (blue) and of its limits: foramen of Monro, stria medullaris thalami, hypothalamic sulcus, habenular commissure, pineal recess, and posterior commissure. Parts of the velar (red) and cisternal surfaces (gray) are also visible. (**B**) The paraterminal, paraolfactory, cingulate, isthmus, and parahippocampal gyri are decorticated. The fornix, the ependymal layer, and the hypothalamic gray matter are removed to expose the fibers of the extracapsular thalamic peduncle. The whole velar surface is now visible. The cingulate and parahippocampal gyri are decorticated and (**C**) successively removed to display the commissural fibers of the corpus callosum, which are then (**D**) cut to expose the lateral ventricle and part of the lateral ventricle surface. (**E**) Peeling away the ependyma from the lateral wall and body of the lateral ventricle reveals the underlying caudate nucleus and the fibers of the tapetum. (**F**) In the layer underneath the tapetum, the fibers of the anterior, superior, and part of the posterior thalamic peduncles are visible. The zonular layer is also removed to expose the thalamic gray matter. To dissect the subthalamic nucleus and the red nucleus, the tegmental white matter must be removed together with the mammillary body from which the mammillothalamic tract originates. (**G**) The course of the mammillothalamic tract serves as a landmark to identify the internal medullary lamina and offers a convenient plane along which the medial thalamic group of nuclei can be cleaved from the lateral thalamic nuclear group. (**H**) The complete removal of the lateral thalamic group of nuclei unveils the laterally coursing fibers of the internal capsule, the most medial portion of which comprises fibers of the thalamic peduncles. The subthalamic nucleus and the substantia nigra are now fully visible. ac, anterior commissure; cc-b, body of the corpus callosum; cc-g, genu of the corpus callosum; cc-r, rostrum of the corpus callosum; cc-s, splenium of the corpus callosum; cg, cingulate gyrus; cn-b, body of the caudate nucleus; cn-h, head of the caudate nucleus; f-b, body of the fornix; ha, habenula; hys, hypothalamic sulcus; ic, internal capsule; lv-a, atrium of the lateral ventricle; lv-b, body of the lateral ventricle; lv-f, frontal horn of the lateral ventricle; m-cp, cerebral peduncle of the midbrain (crus cerebri); mb, mammillary body; mgb, medial geniculate body; mtt, mammillothalamic tract; ot, optic tract; ots, occipitotemporal sulcus; pb, pineal body; pc, posterior commissure; rn, red nucleus; smt, stria medullaris thalami; sn, substantia nigra; st, stria terminalis; stn, subthalamic nucleus; ta, tapetum; th-p, pulvinar of the thalamus; thn-a, anterior thalamic nuclear group; thn-l, lateral thalamic nuclear group; thn-m, medial thalamic nuclear group; thp-a, anterior thalamic peduncle; thp-ec, extracapsular thalamic peduncle; thp-s, superior thalamic peduncle; thp-p, posterior thalamic peduncle.

The ependymal lining of the medial surface of the third ventricle surface is peeled away, disclosing the gray matter of the medial thalamic nuclei and of the hypothalamus. The hypothalamic gray matter is removed, and the column of the fornix is exposed coursing to the mammillary body. The mammillothalamic tract (also known as Vicq d'Azyr tract) is also exposed. This tract joins the mammillary body with the anterior thalamus. Removal of the fornix and most of the superficial layer of thalamic gray matter exposes a relatively thick layer of longitudinally oriented white matter fibers. These originate from the medial thalamic nuclei and are known collectively as the extracapsular thalamic peduncle. They course inferiorly and anteriorly and gather at the anteroinferior margin of the thalamus at the border with the hypothalamus. Here they angle 90° laterally, inferior to the anterior commissure, to enter the ansa peduncularis (Figure 4B).

Dissection resumes to expose the remaining thalamic peduncles. The cingulate and parahippocampal gyri are decorticated, and the U fibers connecting them with the telencephalon are peeled away (Figure 4B). The fibers of the cingulate and parahippocampal gyri, which curve around the corpus callosum, are also removed together with the hippocampal formation (Figure 4C). At this stage, the fibers of the corpus callosum, from the rostrum to the splenium, are exposed and cut laterally, medial to the juncture where the radiations of the corpus callosum meet with the lateral wall of the lateral ventricle. Frontal horn, body, atrium, and temporal horn of the lateral ventricle are now exposed, and the course of the caudate nucleus beneath the ventricular ependyma can be imagined (Figure 4D). The lateral ventricle surface of the thalamus is also visible.

The ependyma is gently peeled from the entire cavity of the lateral ventricle to uncover, in the lateral wall, the course of the caudate nucleus and, posteriorly, the tapetum. The caudate nucleus wraps around the thalamus, lateral to the stria terminalis (Figure 4E), as far as the roof of the temporal horn of the lateral ventricle. The tapetum, a subgroup of splenial fibers, forms the roof and lateral wall of both the atrium and the temporal horn of the lateral ventricle. The subcallosal stratum is recognized in the superior-lateral wall of the lateral ventricle, between the caudate nucleus and the callosal fibers.

Removal of the caudate nucleus, the subcallosal stratum, and the tapetum exposes the fibers of the anterior, superior, and posterior thalamic peduncles (Figure 4F), which emerge and course radially from the thalamus to the telencephalon. Dissection proceeds by removing the stria terminalis and the stratum zonale thalami, exposing the gray matter of the anterior, medial, and posterior thalamic nuclear group and the origin of the thalamic peduncle fibers. Inferiorly, careful and gentle dissection of the white matter of the mesencephalic tegmentum (which consists of the superior cerebellar peduncle, medial lemniscus, and trigeminothalamic and spinothalamic pathways) allows separation of the red nucleus and the more laterally located subthalamic nucleus. Both can be relatively clearly identified because of their firm consistency, which differentiates them from the surrounding white matter. Anterior to both of these nuclei, the craniocaudally directed fibers of the cerebral peduncle are dissected.

The anterior thalamic group of nuclei is removed, following the plane of the internal medullary lamina (Figure 4G). Dissecting the medial from the lateral thalamic group of nuclei along the internal medullary lamina is also feasible, although this is much more difficult. The lamina is extremely thin, and, posteriorly in particular, the consistency and appearance of the thalamic nuclear groups are similar. This phase of dissection is facilitated when performed along the mammillothalamic tract, a very useful anatomic landmark that runs from the mammillary body up to the anterior group of nuclei, maintaining a course within the internal medullary lamina along its entire length.

Finally, removing all the thalamic gray matter reveals the laterally located fibers of the internal capsule (Figure 4H). The fibers of the thalamic peduncles constitute the most medial portion of the internal capsule. Inferiorly, the red nucleus can also be detached exposing the entire extent of the subthalamic nucleus and, more inferiorly, of the substantia nigra. A more lucid perception of the course of the inferior thalamic peduncle depends on dissection of the inferior aspect of a cerebral hemisphere as shown in Figure 5. When a specimen in the same dissection step as in Figure 4E is rotated to expose its inferior aspect, the tail of the caudate nucleus in the roof of the temporal horn can be appreciated (Figure 5A). Laterally, the fibers of the tapetum are seen, building the lateral wall and roof of the temporal horn of the lateral ventricle and, medially, the fibers of the stria terminalis coursing to the amygdala. Further dissection involves detaching the fibers of the tapetum and the gray matter of the tail of the caudate nucleus. This phase reveals, from lateral to medial, the fibers of the posterior thalamic peduncle coursing toward the posterior and the fibers of the inferior thalamic peduncle coursing directly anteroinferiorly toward the temporal pole (Figure 5B). At the final phase, the fibers of the stria terminalis are removed to display the entire course of the fibers of the inferior thalamic peduncle, which can be followed to their origin at the pulvinar (Figure 5C).

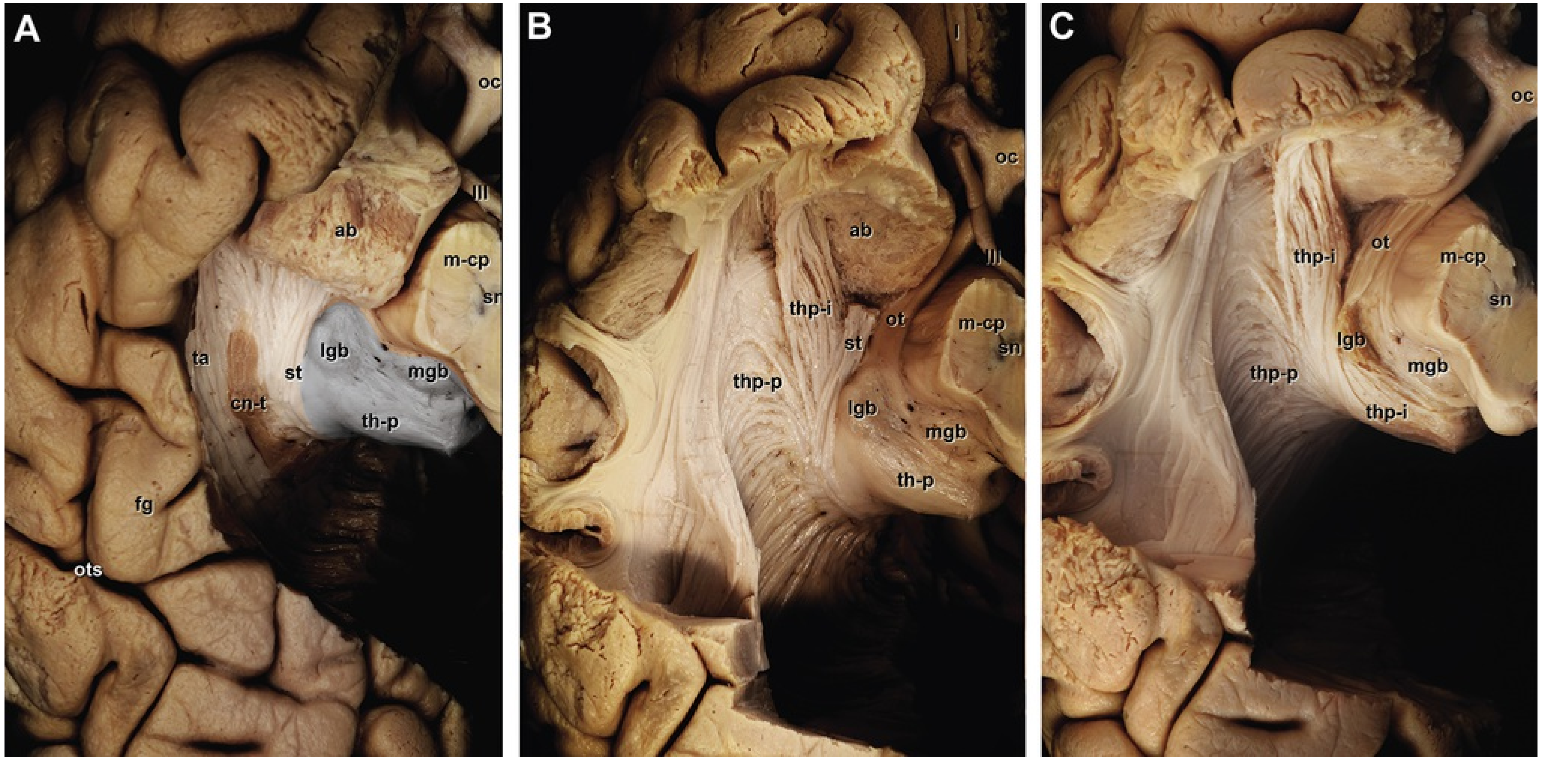


Figure 5 Stepwise dissection of the inferior aspect of a right hemisphere. (**A**) The same anatomy as in Figure 4E. The first layer of the roof of the temporal horn of the lateral ventricle is composed of the tapetum, tail of the caudate nucleus, and stria terminalis. (**B**) The removal of this layer discloses the fibers of the posterior and inferior thalamic peduncles. (**C**) The fibers of the stria terminalis are removed to show the origin from the pulvinar of the fibers of the inferior thalamic peduncle. III, oculomotor nerve; ab, amygdaloid body; cn-t, tail of the caudate nucleus; fg, fusiform gyrus; lgb, lateral geniculate body; m-cp, cerebral peduncle of the midbrain (crus cerebri); mb, mammillary body; mgb, medial geniculate body; oc, optic chiasm; ot, optic tract; ots, occipitotemporal sulcus; sn, substantia nigra; st, stria terminalis; ta, tapetum; th-p, pulvinar of the thalamus; thp-i, inferior-thalamic peduncle; thp-p, posterior thalamic peduncle.

The course of all 5 thalamic peduncles can be visualized in 1 single, slightly oblique view—the extracapsular, anterior, superior, posterior, and inferior thalamic peduncles (Figure 6). There is no method to reliably follow the human thalamic peduncle fibers as far as their cortical termination because they inextricably intermingle with the fibers of the corpus callosum within the sagittal stratum. Similarly, no reliable technique exists to separate the thalamocortical fibers from the laterally situated corticomedullary fibers (which together build the internal capsule). Therefore, as an approximate definition, we grouped the fibers coursing toward the frontal cortex as the anterior thalamic peduncle, the fibers leading toward the central region and anterior parietal cortex as the superior thalamic peduncle, and the fibers directed toward the posterior parietal and occipital cortex as the posterior thalamic peduncle. Included in the posterior thalamic peduncle are some of the fibers that form the temporal loop, commonly known as Meyer loop.[34] The fibers radiating from the pulvinar and continuing to the tip of the temporal lobe (Figure 5C) are part of the inferior thalamic peduncle.

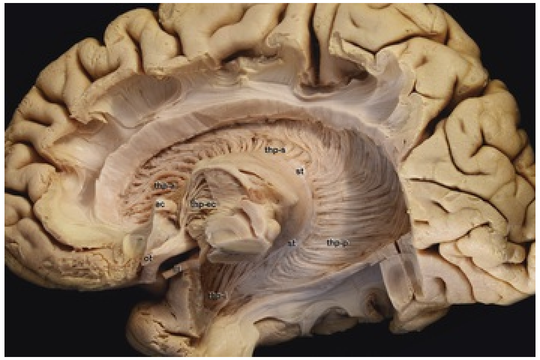


Figure 6 Overview of the 5 thalamic peduncles. III, oculomotor nerve; ac, anterior commissure; ot, optic tract; st, stria terminalis; thp-a, anterior thalamic peduncle; thp-ec, extracapsular thalamic peduncle; thp-i, inferior-thalamic peduncle; thp-s, superior thalamic peduncle; thp-p, posterior thalamic peduncle.

Posterior Aspect

Posterior dissection proceeds along the longitudinal axis of the transverse fissure, with the purpose of showing the neuroanatomic relationships that are relevant for the posterior interhemispheric and infratentorial supracerebellar approaches. The dissection is performed on both sides of a whole-brain specimen. As a reference, the dissection on the left side is 1 stage previous to the right. The dissection (Figure 7A) begins by removing the cuneus on both sides together with the lingual gyrus and the precuneus. The cingulate and parahippocampal gyri are decorticated on the left side and removed completely on the right side. On the left and right sides, the vermian and cerebellar hemispheric cortex between the cerebellomesencephalic and the postclival fissures are removed to expose the dentate nuclei and the superior cerebellar peduncles. On the right side, the most inferomedial tip of the pulvinar, which constitutes part of the cisternal surface of the thalamus, is visible. The limits of the visible cisternal surface at this stage are defined by the splenium of the corpus callosum superiorly, the fimbria of the hippocampus laterally, the collicular brachii and the crus cerebri inferiorly, and the pretectum inferomedially (Figure 7A).

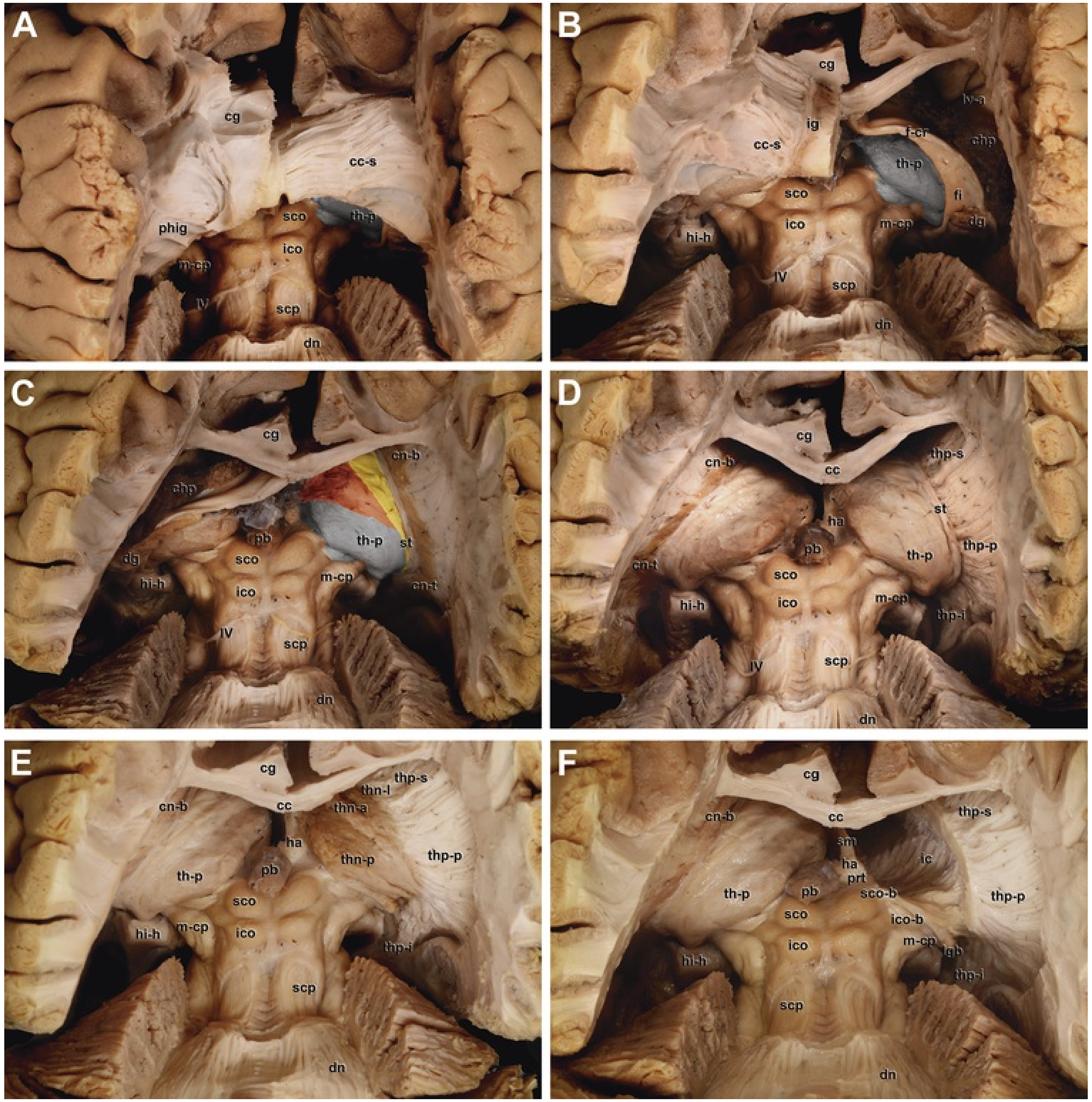


Figure 7 Stepwise dissection of the posterior aspect of a right hemisphere. The illustrations on the left show the preceding step of dissection as an anatomic reference. For the sake of clarity, bilateral structures are labeled on 1 side only. (**A**) Bilateral removal of cuneus, precuneus, and lingual gyrus. Cerebellar cortex and corresponding part of the vermis as far as the postclival fissure are also removed. Parahippocampal and cingulate gyri are removed on the right but only decorticated on the left side. The tip of the cisternal surface (gray) is visible. (**B**) Sharp opening of the atrium of the lateral ventricle by cutting the splenial fibers to illustrate the arching course of the crus and fimbria of the fornix. The whole cisternal surface is now visible. (**C**) Removal of choroid plexus, fornix, and ventricular ependyma discloses the lateral ventricle (yellow) and the velar (red) surfaces. The superior tela choroidea of the velum interpositum is demonstrated. Removal of (**D**) the caudate nucleus and superior tela choroidea and (**E**) the zonular layer and stria terminalis to expose the thalamic peduncles and the thalamic groups of nuclei. (**F**) Removal of thalamic gray matter to expose the internal capsule. IV, trochlear nerve; cc, corpus callosum; cc-s, splenium of the corpus callosum; cg, cingulate gyrus; chp, choroid plexus; cn-b, body of the caudate nucleus; cn-t, tail of the caudate nucleus; dg, dentate gyrus; dn, dentate nucleus; fi, fimbria; ha, habenula; hi-h, head of the hippocampus; ic, internal capsule; ico, inferior colliculus; ico-b, brachium of the inferior colliculus; ig, indusium griseum; lgb, lateral geniculate body; lv-a, atrium of the lateral ventricle; m-cp, cerebral peduncle of the midbrain (crus cerebri); pb, pineal body; phig, parahippocampal gyrus; prt, pretectum; sco, superior colliculus; sco-b, brachium of the superior colliculus; scp, superior cerebellar peduncle; smt, stria medullaris thalami; st, stria terminalis; th-p, pulvinar of the thalamus; thn-a, anterior thalamic nuclear group; thn-l, lateral thalamic nuclear group; thn-p, posterior thalamic nuclear group; thp-i, inferior-thalamic

peduncle; thp-s, superior thalamic peduncle; thp-p, posterior thalamic peduncle.

A thin mantle of gray matter, the indusium griseum, overlays the surface of the splenium of the corpus callosum (Figure 7B). The longitudinal striae are visible continuing posteriorly into the fimbria. Fasciola cinerea, dentate gyrus, and fimbria all are severed, together with the splenial fibers, to open the atrium of the lateral ventricle. Applying this process, the entire route of the fimbria is exposed, from the hippocampal commissure as far as the hippocampus head as it arches around the pulvinar, and serves as a separation between the cisternal and lateral ventricle surfaces of the thalamus.

The entire cisternal surface of the thalamus (within the quadrigeminal and ambient cisterns), formed by the pulvinar and the geniculate bodies, is now clearly visible. Medially, the margin of the cisternal surface is bordered by the stria medullaris, habenular commissure, pineal recess, and posterior commissure. Anteromedially, these same structures separate the cisternal surface from the velar surface. The superolateral margin is defined by the fornix, the anterolateroinferior margin is defined by the medial curve of the head of the hippocampus, and the inferior margin is defined by the brachii of the superior and inferior colliculi and the crus cerebri.

Removing the fimbria and the choroid plexus (Figure 7C), the lateral ventricle surface is exposed as far as the stria terminalis. Medially, the superior tela choroidea is demonstrated, which forms the roof of the velum interpositum and, at its attachment to the taenia choroidea, marks the limits between the lateral ventricle and the cisternal and the velar surfaces of the thalamus. More laterally, after removing the ventricular ependyma, the curving course of the caudate nucleus around the thalamus is clearly identified. The caudate nucleus is removed together with the tapetum to disclose the course of the superior, posterior, and inferior thalamic peduncles. Medially, the superior tela choroidea is totally removed to show access to the velum interpositum (Figure 7D). Peeling away the zonular layer of the thalamus uncovers the gray matter of the posterior, anterior, and lateral thalamic groups of nuclei (Figure 7E). These nuclei are bordered medially by the habenular commissure and stria medullaris and inferomedially by the pretectal area and the brachii of the superior and inferior colliculi. Laterally, the fibers of the thalamic peduncles emerge from the thalamic gray matter to course laterally into the internal capsule (Figure 7F).

Surgically Accessible Surfaces of the Thalamus

Dissection along the trajectories described in the previous paragraphs reveals only the free surface of the thalamus, which is approximately 50% of the thalamic surface. The remainder is covered laterally by the internal capsule and caudally by the mesencephalon and pretectum (Figure 8A and B). These dissections clearly establish that the free thalamic surface is topographically subdivided into various smaller surface areas according to their relationships with the following principal anatomic landmarks, which become important to recognize during surgical exploration: stria terminalis, taenia choroidea, fornix, and stria medullaris thalami. These landmarks define the distinct surfaces of the thalamus: the lateral ventricle surface, the velar surface, the cisternal surface, and the third ventricle surface (Figure 9A–C).

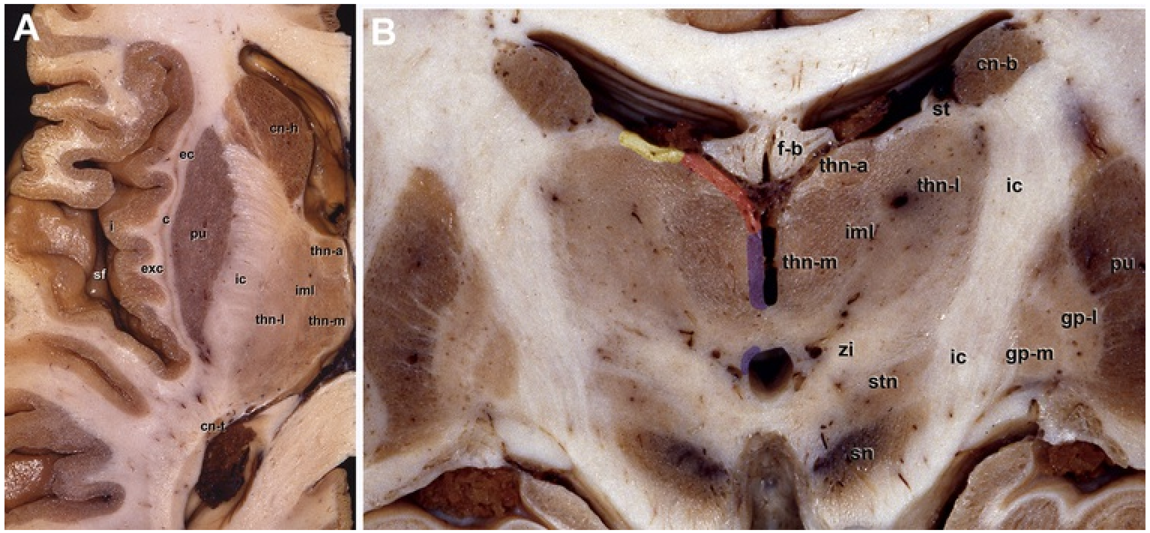


Figure 8 Axial (**A**) and coronal (**B**) sections of the thalamus. The lateral and ventral surfaces, which make up approximately 50% of the thalamic surface, are covered by the internal capsule, prethalamus, and mesencephalon. The lateral ventricle surface is indicated by yellow; the velar surface, by red; and the third ventricle surface, by blue. c, claustrum; cn-b, body of the caudate nucleus; cn-h, head of the caudate nucleus; cn-t, tail of the caudate nucleus; ec, external capsule; exc, extreme capsule; f-b, body of the fornix; gp-l, lateral segment of globus pallidus; gp-m, medial segment of globus pallidus; i, insula; ic, internal capsule; iml, internal medullary lamina; pu, putamen; sf, sylvian fissure; sn, substantia nigra; st, stria terminalis; stn, subthalamic nucleus; thn-a, anterior thalamic nuclear group; thn-l, lateral thalamic nuclear group; thn-m, medial thalamic nuclear group; zi, zona incerta.

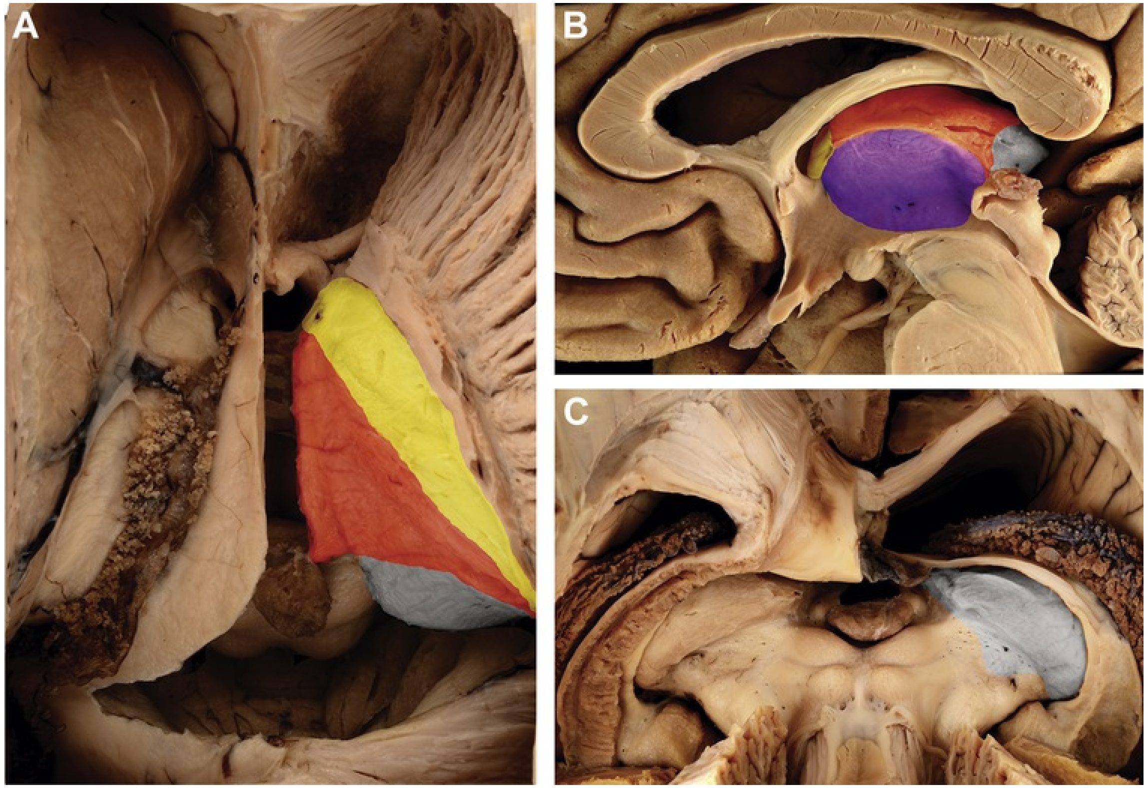


Figure 9 The free thalamic surfaces as visible from superior (**A**), medial (**B**), and posterior (**C**) views. The lateral ventricle surface is indicated by yellow; the velar surface, by red; the cisternal surface, by gray; and the third ventricle surface, by blue.

The lateral ventricle surface is located between the stria terminalis laterally and the taenia choroidea medially. The taenia choroidea separates the lateral ventricle surface from the velar surface anteriorly and the cisternal surface posteriorly. The lateral ventricle surface of the thalamus culminates anteriorly at the foramen of Monro, where the stria terminalis and the column of the fornix meet. Posteriorly, the lateral ventricle surface narrows progressively, as the stria terminalis and the taenia choroidea continue on a converging and arching course around the pulvinar. At this point, it comprises the anterior wall of the atrium and continues inferolaterally where it builds the medial part of the roof of the temporal horn, which is situated in the deepest part of the choroidal fissure where the stria terminalis and fimbria meet a short distance before the inferior choroidal point.

The margins of the third ventricle surface are defined by the stria medullaris thalami, on its superior and on most of its anterior and posterior borders. The stria medullaris thalami curves posteriorly from its origin at the foramen of Monro as far as the habenular nuclei. The remainder of the posterior border is defined, in a cranial-to-caudal direction, by the habenular commissure, the pineal recess, and the posterior commissure. The hypothalamic sulcus demarcates the inferior border as it curves from the superior extremity of the cerebral aqueduct to the foramen of Monro.

The cisternal and the velar surfaces are located adjacent to the cisterns of the transverse fissure. The cisternal surface is adjacent to the quadrigeminal and ambient cisterns (i.e., to the origin and lateral wings of the transverse fissure), whereas the velar surface is adjacent to the cistern of the velum interpositum (i.e., to the superior median limb of the transverse fissure). The cisternal surface corresponds to the part of the pulvinar medial to the fimbria and medial and lateral geniculate bodies. The lateral border is defined by the taenia choroidea, which can be accessed surgically from a posterior approach, by proceeding along the deepest part of the choroidal fissure. Removing the fornix also reveals the lateral border of the cisternal surface. Therefore, for surgical orientation, the crus of fornix and the fimbria mark the superolateral border of the cisternal surface, and the head of the hippocampus marks the inferoanterolateral extremity of the cisternal surface. Superomedially, the cisternal surface continues into the velar surface above the habenular commissure. Below the habenular commissure, the medial border continues in the lateral margin of the pineal recess and the posterior commissure. In a medial-to-lateral direction, the inferior border is defined by the remaining part of the pretectal area, the brachii of the superior and inferior colliculi, and, more laterally, the crus cerebri. The anteroinferior border is defined by the anterior limit of the lateral geniculate body.

The velar surface is located between the taenia choroidea and the stria medullaris thalami. It is enclosed between the dorsal and ventral limits of the choroidal fissure, and therefore it can be designated as a surface of the thalamus that creates the lateral wall of the velum interpositum. The velar surface terminates anteriorly, a short distance from the foramen of Monro, where the superior tela choroidea and inferior tela choroidea of the velum interpositum fuse. Posteriorly, it is not always continuous with the cisternal surface. Being covered by the fornix, the velar surface can be reached only by opening the choroidal fissure.

In our specimens, the third ventricle surface was always the largest, followed by the cisternal and velar surfaces. The lateral ventricular surface, which in every specimen was very narrow, was the smallest in all cases.

Discussion

The term thalamus derives from the ancient Greek θάλαμος meaning "chamber" and at that time referred to the innermost room of Greek mansions, usually reserved for the bridal couple. Its first use in a medical context is attributed to Galen of Pergamon (130–201 AD). In his "*De usu partium*,"[35] Galen described a "thalamus of the ventricles," which corresponded to the region where the lateral ventricles join together and from which the optic nerves originate. Probably because of its location deep in the brain, the anatomy and function of the thalamus remained obscure throughout the Renaissance and most of the modern age. The seminal studies of Burdach[11] in 1822 resulted in the first description of the inner thalamic architecture. Later in 1865, Luys[14] indicated that the role of the thalamus resembled a sensory relay station. He also illustrated its three-dimensional morphology. Later, technologic improvements to various dyes and the introduction of the first retrograde degeneration studies and neurophysiologic methods led to a gradual but steady transfer of focus from macroscopic to microscopic anatomy and to studying the function and connections of the thalamus,[6] an approach that persists today. In clinical practice, this led to diverse, often overlapping classifications and conceptualizations of thalamic anatomy, with descriptions according to microscopic histologic aspects (i.e., several stereotactic atlases[36,37]), neuroradiologic views[38] (including probabilistic parcellation[39] and high-field visualization[40,41]), and neurophysiologic perspectives.[6]

This impressive number of studies encompassing a variety of perspectives (histologic, neurophysiologic, neuroradiologic, based on humans and experimental animals) led to significant improvements in understanding of the architecture and function of the thalamus and, to some extent, increased our knowledge, but occasionally caused confusion. For instance, the nomenclature of the thalamic nuclei and connections was inconsistent—1 particular structure being known by different names or 1 name being applied to several different structures. All these studies, observations, and investigations are of limited value to the neurosurgeon. To access the human thalamus successfully, avoiding damage to neighboring neural tissue, a detailed, illustrated description of the human thalamus topography and surrounding neural anatomy is decisive.

Nomenclature Quandary

The main disputes regarding nomenclature pertain to the thalamic nuclei and peduncles. A review of thalamic nuclei nomenclature by Hirai and Jones[42] revealed that 2 groups of nomenclature were adopted. The first by Friedemann[43] (later revised by Hirai and Jones[42]) relied on the connectivity pattern of the thalamus in nonhuman primates, whereas the nomenclature established by Vogt and Vogt[44] (later popularized by Schaltenbrand et al.[37]) was based on cytoarchitectonic criteria of the human thalamus. At the present time, a process of seeking a unifying nomenclature that encompasses both cytoarchitectonic and connectivity patterns is in progress, a concept adopted in the present study.[36,45]

A parallel problem exposes disagreement in the literature regarding the terminology of the thalamic peduncles and the fibers included in each peduncle. As demonstrated in our dissections, no reliable macroscopic method exists either to unequivocally determine the cortical termination of the fibers within the thalamic peduncles or to distinguish them from the laterally located corticomedullary fibers that together build the internal capsule. The only possible method to evaluate this complex anatomy is to separate the fibers into segments according to their orientation, a method that we implemented in our study.

The bundle of fibers connecting the medial thalamus with the amygdala and the anterior temporal cortex has been accorded several names, including stilus internus,[46] inferior thalamic peduncle,[47] and extracapsular thalamic peduncle.[48] For clarity, we advocate the nomenclature proposed by Klingler and Gloor[48] as being most relevant; therefore, we reserved the term "inferior thalamic peduncle" to describe the fibers connecting the pulvinar with the anterior temporal cortex, which proceed in the sublenticular segment of the internal capsule (Figure 5C). The term "extracapsular thalamic peduncle" describes the fibers originating from the third ventricle surface of the thalamus that join the ansa peduncularis, inferior to the anterior commissure, to reach the amygdala and temporal cortex (Figure 4B–F). This term was chosen to emphasize the extracapsular course of these fibers as opposed to the fibers of the anterior, superior, posterior, and inferior peduncles, which proceed on the medial side of the internal capsule.

Topographic Classification of Surgical Surfaces of the Thalamus

Complying with accepted morphologic descriptions,[2-4] 6 thalamic surfaces are described according to standard anatomic axes. Of these, the superior surface, medial surface, and posterior surface are free surfaces adjoining the ventricular cavities or cisternal spaces, whereas the anterior surface, lateral surface, and most of the inferior surface are covered by the internal capsule, the prethalamus, and the mesencephalon. The thalamus itself displays no definitive intrinsic landmarks that identify the borders between these various surfaces. However, as demonstrated in our dissections, clear boundaries that demarcate the free thalamic surface can be identified by observing the relationship of the thalamus to neighboring structures (stria terminalis, taenia choroidea, fornix, and stria medullaris thalami). Thus, the free surface has been divided into 4 areas: lateral ventricle surface, velar surface, cisternal surface, and third ventricle surface.

This classification constitutes an important anatomic pattern to observe and understand and has far more surgical relevance than the cytoarchitectonic,[37] functional,[42,43] embryologic,[8,9] and neuroradiologic classifications.[38,39] First, the above-described landmarks are clearly visible in anatomic specimens, on neuroimaging (both morphologic and functional[49]), and intraoperatively. Second, each thalamus surface has a defined relationship with the underlying main groups of nuclei. Therefore, the proposed zones of the thalamic surface are decisive when defining the precise preoperative topographic diagnosis of a thalamic pathology and are subsequently a relevant aspect to incorporate into surgical strategy, especially when deciding the most appropriate approach.

Surgical Approaches to the Thalamus

When considering surgery for lesions of the thalamus, the choice of approach is significant because this judgment can be a deciding factor with regard to patient outcome.[28-30,38,50-55] A thalamic lesion is accessed most effectively by an approach specific to 1 of the 4 free surfaces described that borders on or is compromised by the lesion. Preoperative imaging, including diffusion tensor imaging as long as the normal anatomy is not excessively distorted by the tumor, to identify the borders of each of the 4 surfaces relative to the targeted lesion.

Applying the precept of reducing damage to normal tissue diminishes the risk of postoperative morbidity. Following these principles to design an optimal approach via a route that minimizes damage to normal structures is particularly challenging. Only approximately 50% of the thalamic surface can be visualized at surgical exploration. The remainder is covered by the internal capsule, the prethalamus, and the mesencephalon and cannot be accessed surgically because the integrity of these significant structures would be disrupted.

Based on these considerations, transcortical surgical approaches are not recommended. Transcortical approaches and their several variations are widely endorsed in the neuro-oncologic literature[50-56] to explore lesions located at the lateral ventricle and third ventricle surfaces. Applying these approaches can lead to undesirable postoperative consequences for the patient because normal neural structures along the pathway from the cortical incision to the lesion will be damaged. The morbidity of transcortical approaches for thalamic lesions (e.g., hemiparesis, hemianopia) is evident and well documented in the literature.[51,52,54,55] The risk of epileptogenicity resulting from transcortical approaches is not negligible.[57]

Exploiting the various cisternal pathways offers ideal access to the lesion and avoids damage to normal brain structures.[58] In light of this concept and given the anatomic location of the thalamus, the interhemispheric fissure and the transverse fissure[59] provide the most logical access to the thalamus through either a transcallosal or a transcisternal approach. The anterior interhemispheric transcallosal approach provides access to the portion of the lateral ventricle surface of the thalamus located in the body of the lateral ventricle by severing only a very small part of the callosal fibers. The third ventricle surface of the thalamus can be accessed transforaminally[60] via the foramen of Monro. The velar surface of the thalamus can also be reached by opening the choroidal fissure between the fornix and choroid plexus, which results in a broader exposure of the thalamic surface. Transcisternal pathways (infratentorial supracerebellar and posterior interhemispheric) offer direct access to the cisternal surface of the thalamus, avoiding damage to any neural structures.

When determining the approach and surgical strategy to explore and remove lesions of the thalamus, several other factors are critical to consider. The growth pattern is relevant. In particular, expansive lesions distort the surrounding anatomic features significantly and subsequently complicate the approach and can mislead intraoperative orientation. Studying the venous and arterial vascular anatomy is of prime importance, particularly the thalamic vasculature. Furthermore, competence in microneurosurgical techniques and a detailed knowledge of brain anatomy as applied to neurosurgery are fundamental and essential prerequisites before pursuing surgery for lesions of the thalamus.

Conclusions

The anatomic topographic relationships of the thalamus with the stria terminalis, taenia choroidea, fornix, and stria medullaris thalami were applied to divide the free thalamus surface into 4 distinct zones: the lateral ventricle surface, the velar surface, the cisternal surface, and the third ventricle surface. This proposed topographic zoning of the thalamic surface is based on anatomic and neuroradiologic data. In addition, the 4 specific anatomic landmarks described are clearly visible and recognizable intraoperatively and are of special significance. Possessing this anatomic knowledge and appropriate radiologic data enables the neurosurgeon to define precisely the location of thalamic pathologies. Correlating the anatomic, radiologic, and surgical principles discussed in this article can guide and support the planning of the most appropriate and balanced surgical strategy.

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Queries and Answers

Query: If there are any drug dosages in your article, please verify them and indicate that you have done so by initialing this query

Answer: there are no drug dosage in the article

Query: In article title, OK to change “Thalamus” to the adjective form “Thalamic” before “Surfaces”?

Answer: If possible we'd like to keep "Thalamus surface"

Query: Is the last sentence of Abstract, “These proposed surface divisions, based on recognizable anatomic landmarks, can provide more reliable surgical orientation,” OK as edited?

Answer: ok as edited

Query: In the sentence “Despite the advanced technology available today, most of the applicable literature concentrates on the anatomy of nonhuman vertebrates only,” OK to change “advanced technical features” to “advanced technology”?

Answer: ok as edited

Query: Is the sentence “A comprehensive knowledge of anatomy is essential to successfully performing precise microneurosurgical procedures” OK as edited?

Answer: ok as edited

Query: In the text “These fibers are also known as the stria longitudinalis medialis corporis callosi (or stria of Lanci),” are changes in stria names OK per Dorland’s?

Answer: NO. The name is "stria longitudinalis medialis of Lancisi". Please, return to the former version: "These fibers are also known as the medial longitudinal stria (or stria longitudinalis medialis of Lancisi) and lateral longitudinal stria."

Query: Please review the sentence “Preoperative imaging, including diffusion tensor imaging as long as the normal anatomy is not excessively distorted by the tumor, to identify the borders of each of the 4 surfaces relative to the targeted lesion.” A verb is needed before “to identify.”

Answer: You are perfectly right. Thank you for your job! the verb is "allows" so the sentence becomes "Preoperative imaging, including diffusion tensor imaging as long as the normal anatomy is not excessively distorted by the tumor, ALLOWS to identify the borders of each of the 4 surfaces relative to the targeted lesion."

Query: Some references have been renumbered because of duplicate references in original list. The duplicates have been removed, and the References list and in-text citations have been renumbered as appropriate; OK?

Answer: ok, thank you

Query: Please provide abbreviated journal name for ref. 8. I couldn’t found it on pubmed.

Answer: Please see this link: http://onlinelibrary.wiley.com/doi/10.1002/cne.920200502/abstract At that time the journal name was "Journal of comparative neurology and psychology" as you can see in the bottom of the title page of the paper. Over the years it changed name and now it is called just "journal of comparative neurology". I think the original name would be the correct one, but please, feel free to decide which is more appropriate

Query: Please note that the refs. 11, 12, 13, 14, 15, 18, 35, 43 and 46 are in other language. Please provide the English version of these references and also provide the missing information in those refs. if any.

Answer: There are no english versions of any of these references. I provided missing information as required. Please note that also 12 and 46 are duplicate 11. K.F. Burdach, *Vom Baue und Leben des Gehirns*, 1822, Dyk Verlag, Leipzig; 162–181. 12: Meynert T. *Psychiatrie; Klinik der Erkrankungen des Vorderhirns begruendet auf dessen Bau, Leistungen und Ernaehrung*. erste Hälfte, 1884, Wilhelm Braumueller Verlag,Wien: 1–125. 13 Foville AL. *Traité complet de l'anatomie, de la physiologie et de la pathologie du système nerveux cérébro-spinal: 1. ptie., Anatomie*. Fortin, Masson, Paris; 1844 14 Luys J. *Iconographie photographique des centres nerveux: ouvrage accompagné d'un atlas de soixante-dix photographies et de soixante-cinq schémas lithographiés*. Atlas de soixante-dix photographies: avec soixante-cinq lithographiés. Baillière, Paris; 1873 15 Forel A. *Untersuchungen über die Haubenregion und ihre oberen verknüpfungen im Gehirne des Menschen und einiger Säugethiere: mit Beiträgen zu den Methoden der Gehirnuntersuchung*. Arch für Psychiatrie und Nervenkrankheiten 7: 392-495; 1877 18 Wolf-Heidegger G. *Atlas der systematischen Anatomie des Menschen: Systema nervorum; Vasa sanguinea et lymphatica*. Vol. III. Basel: Karger; 1962. 35: Galenus. *De usu partium corporis humani libri XVII*. Basilea: Apud Gulielmum Rovillium; 1533. 43 Friedemann M. *Die Cytoarchitektonik des Zwischenhirns der Cercopitheken mit besonderer Berücksichtigung des Thalamus opticus*. J. Psychol Neurol 18: 309-378 (1911) 46 Meynert T. *Psychiatrie; Klinik der Erkrankungen des Vorderhirns begruendet auf dessen Bau, Leistungen und Ernaehrung*. 1884, Wilhelm Braumueller Verlag, Wien: 1–125.

Query: Please check the volume number in refs. 29 and 30, 46 and correct if necessary.

Answer: 29: IVB is correct 30: IVA is correct 46: has been corrected. It is vol 1 which in german is "erste hälfte"

Query: Please provide abbreviated journal title for ref. 47.

Answer: The journal does not exist any more. I do not know which is the official abbreviation. Arch of Neur and Psych? you can find the article at the following link http://jamanetwork.com/journals/archneurpsyc/issue/5/4

Query: For reference 58 (Harput and Türe), please provide complete updated details regarding publication status; if still in press, please provide journal title.

Answer: The ref 58 is still in press by "Neurosurgery"

Query: Please confirm your conflict of interest statement is correct.

Answer: correct

Query: Is a credit line from a previously published source needed for Figure 1? If yes, please provide complete credit line and submit written permission when returning your author proof.

Answer: I beg your pardon. You mean we need written permission from the Wolf-Heidegger book or from the Josef Klingler of 1941? In both cases are very old books, wow can we know if a permission is needed? could you help us?

Query: In Figure 2 legend text “fiber tracts pertaining to the thalamic radiations are represented with square sections,” OK to replace “those” with “fiber tracts”?

Answer: ok! thank you

Query: Is a credit line from a previously published source needed for Figure 2? If yes, please provide complete credit line and submit written permission when returning your author proof. OK to add reference citation 17 to legend where book title is mentioned? Is the source for Figure 2 Krieg and Mark?

Answer: no, it is not needed. The author published the atlas at own expenses in limited editon and sent it as a present to several library in USA clearly stating in the introduction of the book that he wanted the books and its content to be freely available to anyboby

Query: Is Table 1 title OK as added? and also check the layout.

Answer: ok

Query: In Table 1, are abbreviations STN and SN correctly spelled out in footnote?

Answer: yes

Query: Please provide volume number if any for ref. 31.

Answer: volume 36. Thanks for your checking

Query: Refs. 12 and 46 are found to be identical with slight variation in page range. Please check and amend if necessary.

Answer: Amended (please see answer to query 10)

Query: Please confirm that given names and surnames have been identified correctly.

Answer: correct